The Future of Particle Astrophysics at Fermilab

Fermilab's mission statement:

To ``advance the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high energy physics and related disciplines"

The Particle Astrophysics program at FNAL is and must remain consistent with this mission. It provides probes of fundamental physics that complement accelerator experiments.

Evidence for Physics beyond the Standard Model

- Neutrino Masses: atmospheric and solar neutrino experiments
- Dark Matter: non-baryonic particles (possibly SUSY)
- Dark Energy: acceleration of the Universe may be a signal of vacuum energy, a new light particle, or the breakdown of General Relativity at large scales (perhaps associated with extra dimensions)
- Large-scale Structure: new physics at 10^{15} GeV (inflation) or something even more exotic (colliding branes)
- Ultra-High Energy Cosmic Rays? 10^{11} GeV particles

Today's Lineup

Astrophysics Center and Theory	Scott Dodelson
SNAP	Peter Limon
Optical Cosmology: SDSS & Beyond	Jim Annis
Ultra-high Energy Cosmic Rays	Angela Olinto
Dark Matter Searches	Dan Bauer
Discussion & Other opportunities	Josh Frieman

Particle Astrophysics at Fermilab

Twenty years ago, Fermilab presciently began an Astrophysics effort—Theoretical Astrophysics.

In recent years, other National Laboratories have followed suit and are building major programs (LBNL, SLAC, Brookhaven, …)

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The field is vibrant and expanding, and new projects are increasingly on a scale beyond that of University groups. How can we best serve particle astrophysics Users and at the same time play significant scientific leadership roles?

Key Questions: Quarks to the Cosmos

1. What is the nature of the Dark Energy driving the acceleration of the Universe?

Determine Dark Energy equation of state:

- Supernovae (SNAP)
- Weak Lensing, ISW (CTIO, SNAP, LSST,…)
- Galaxy Clusters counts (optical, WL, SZ, X-ray)
- Galaxy redshift surveys: standard rulers (KAOS)
  Lyman-alpha forest

Tests of General Relativity on large scales:

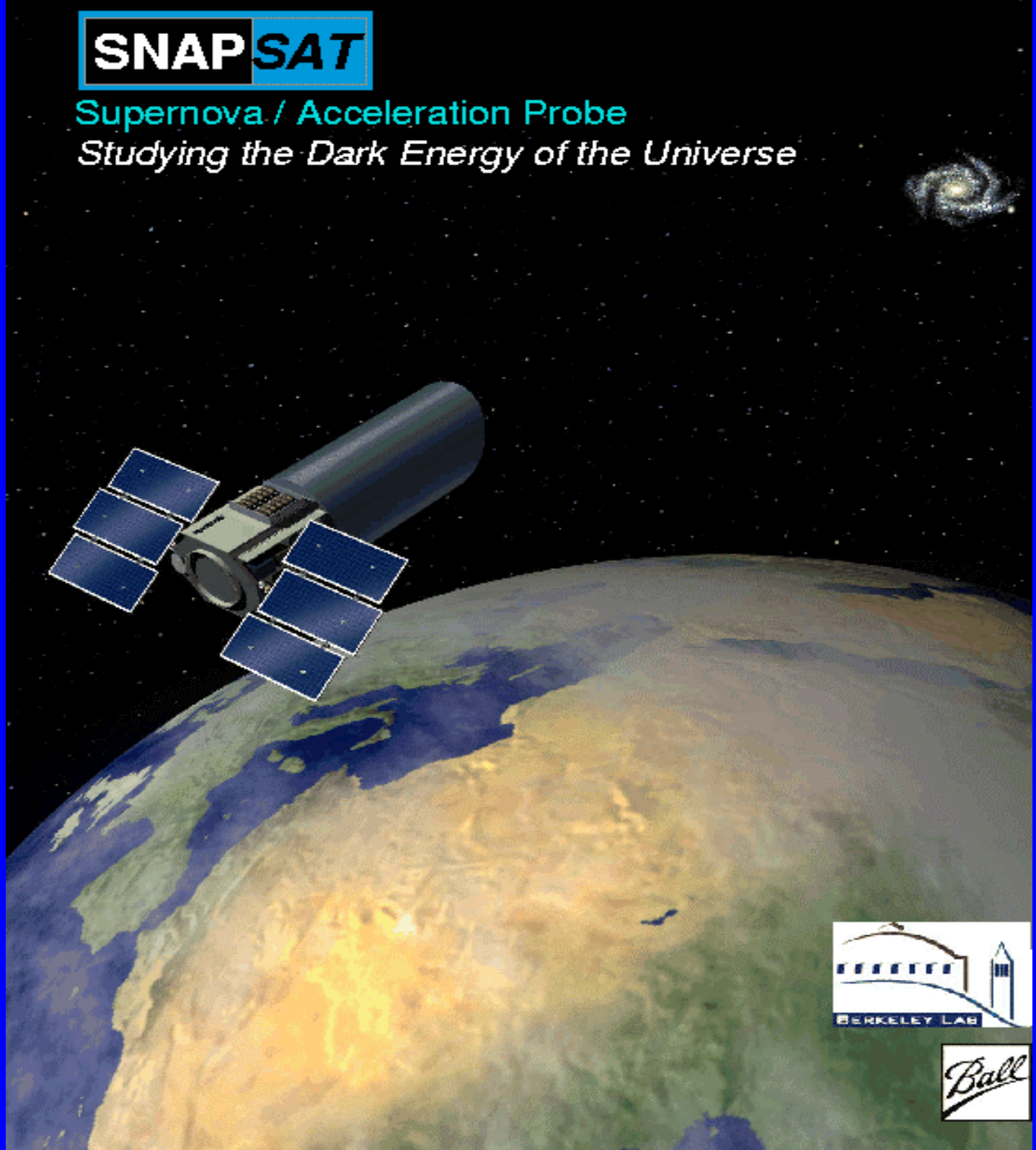
- Solar system (Lunar laser ranging)
- Cosmological scales (growth of structure)

Proposed satellite mission to observe ~3000 SNe Ia out to $z \sim 1.7$

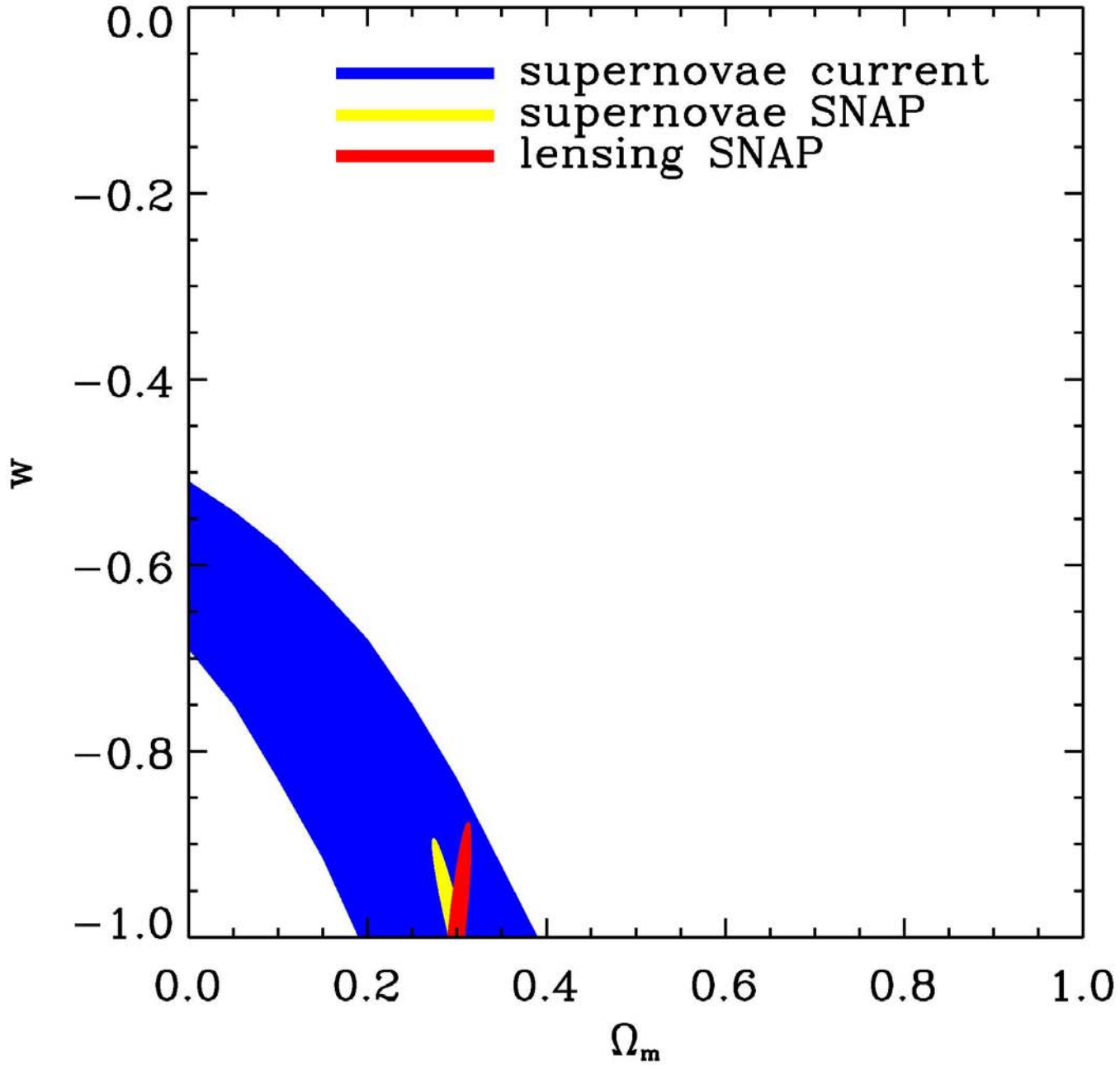
Why Space?

$z > 1$ (NIR)

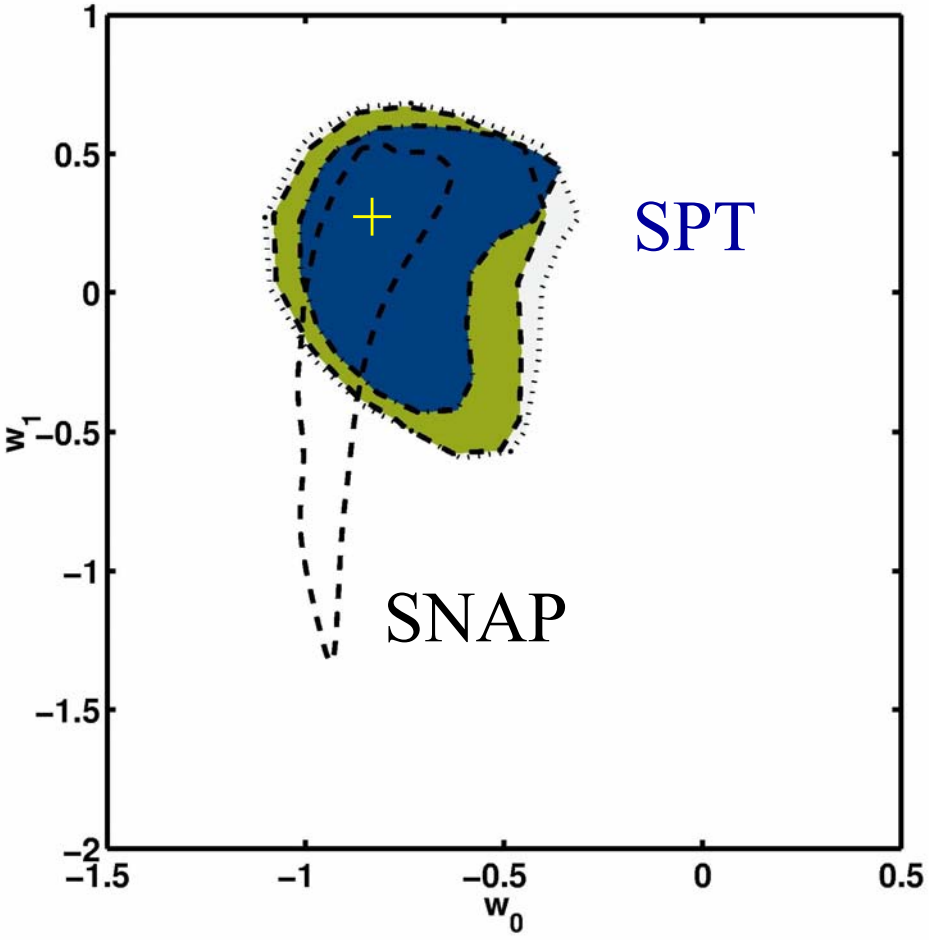
Control systematics

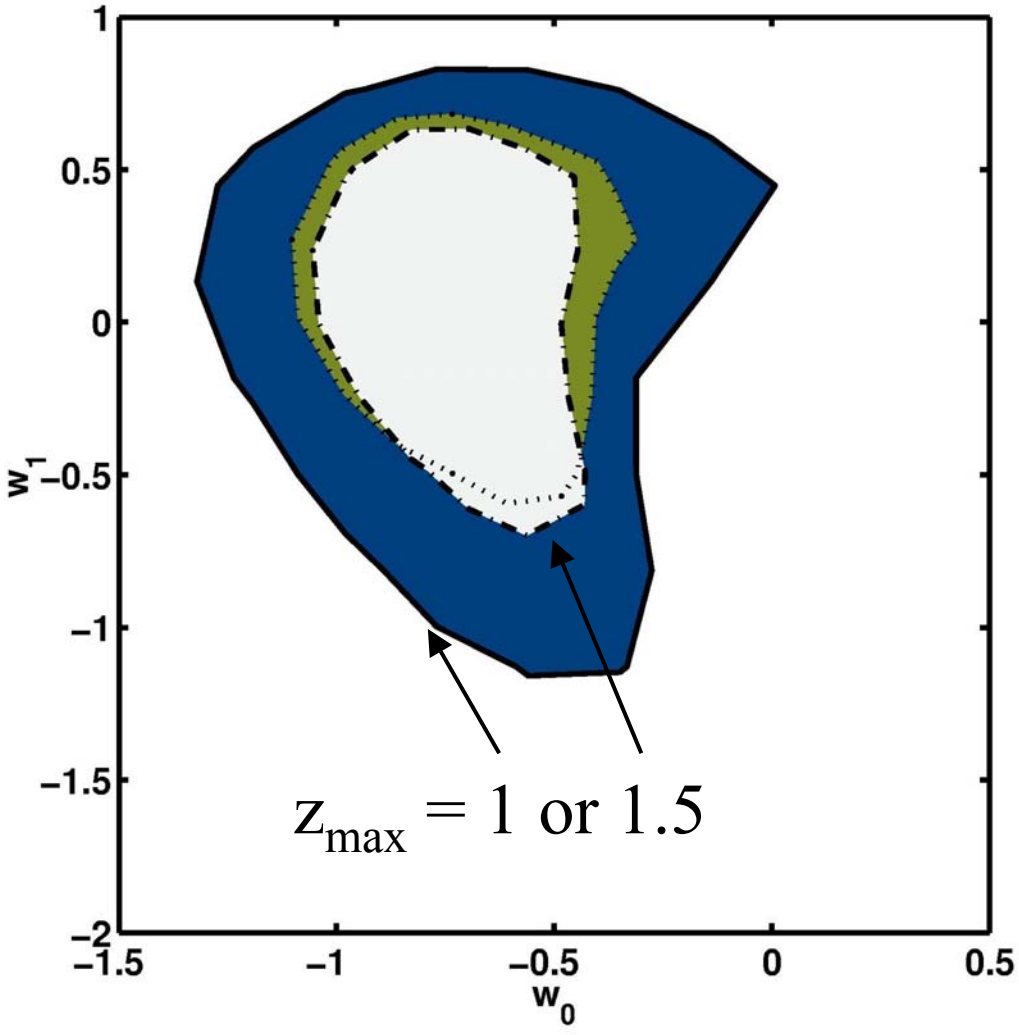


Parameter Complementarity



Constraints from Cluster Counts on Dark Energy





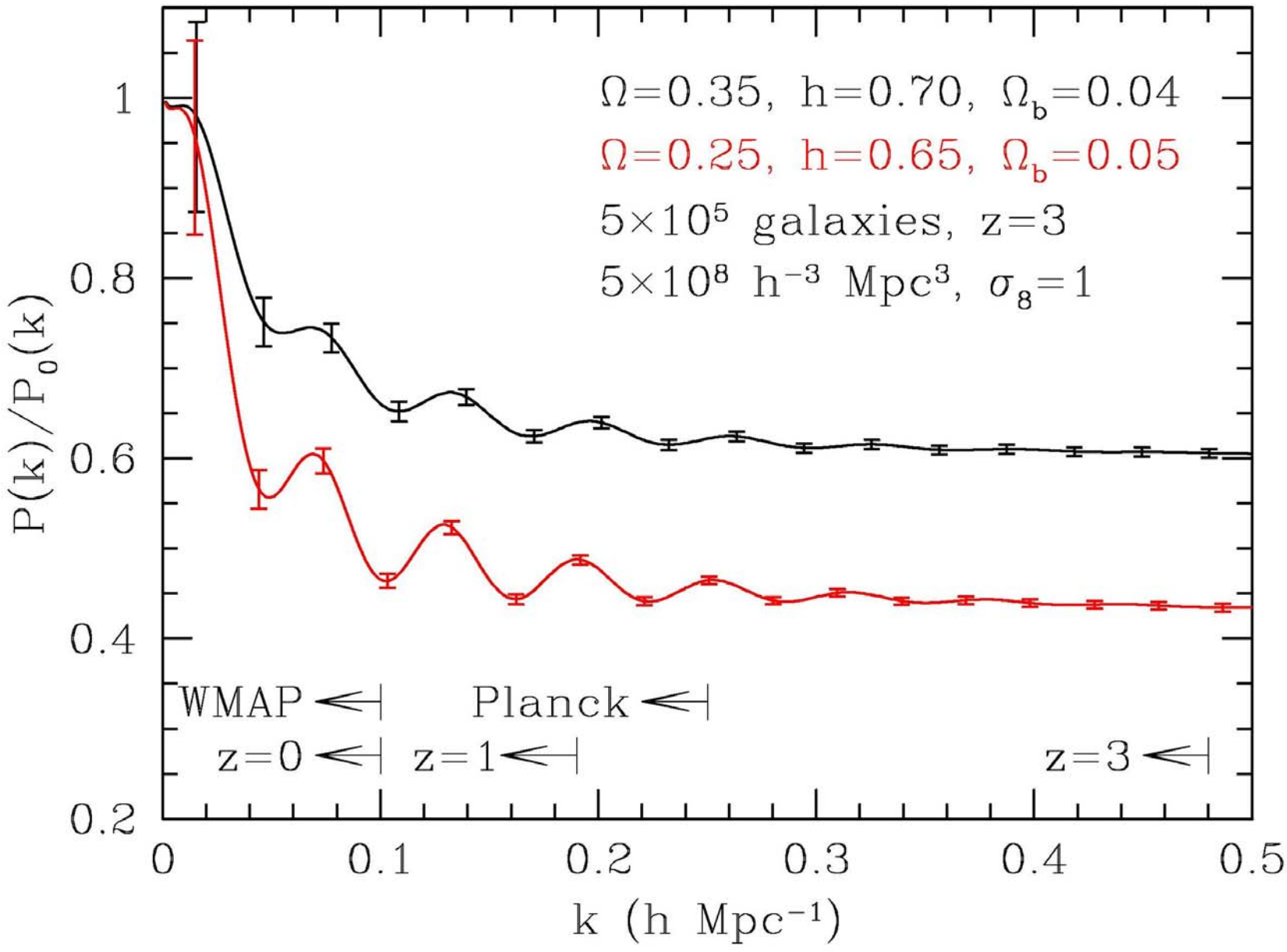
CTIO survey

Battye & Weller

Baryon Oscillations In the Matter Power Spectrum: Standard Ruler

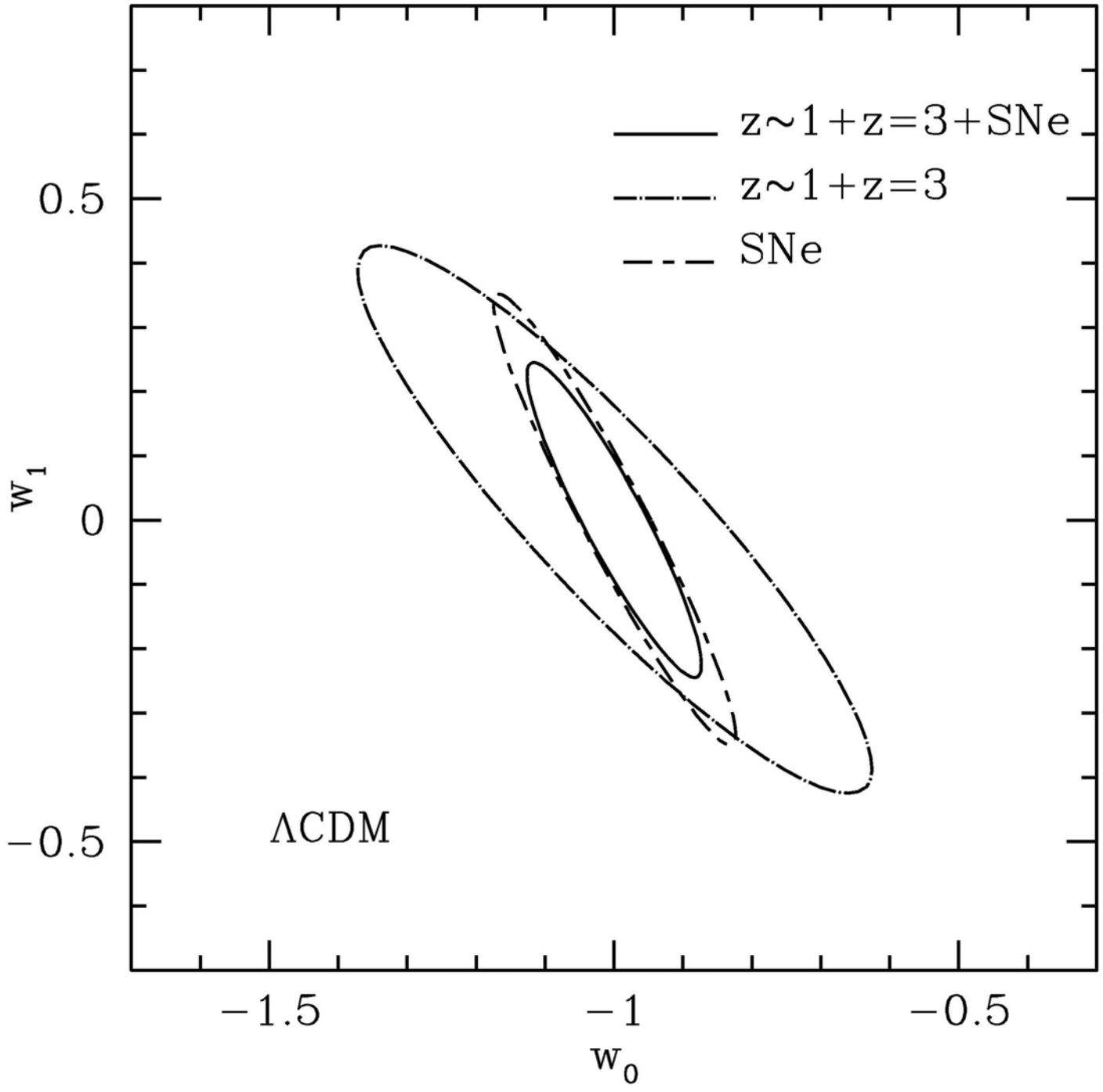
Seo & Eisenstein

Hu & Haiman



Parameter Constraints from future deep Galaxy Redshift Surveys (KAOS)

Seo & Eisenstein



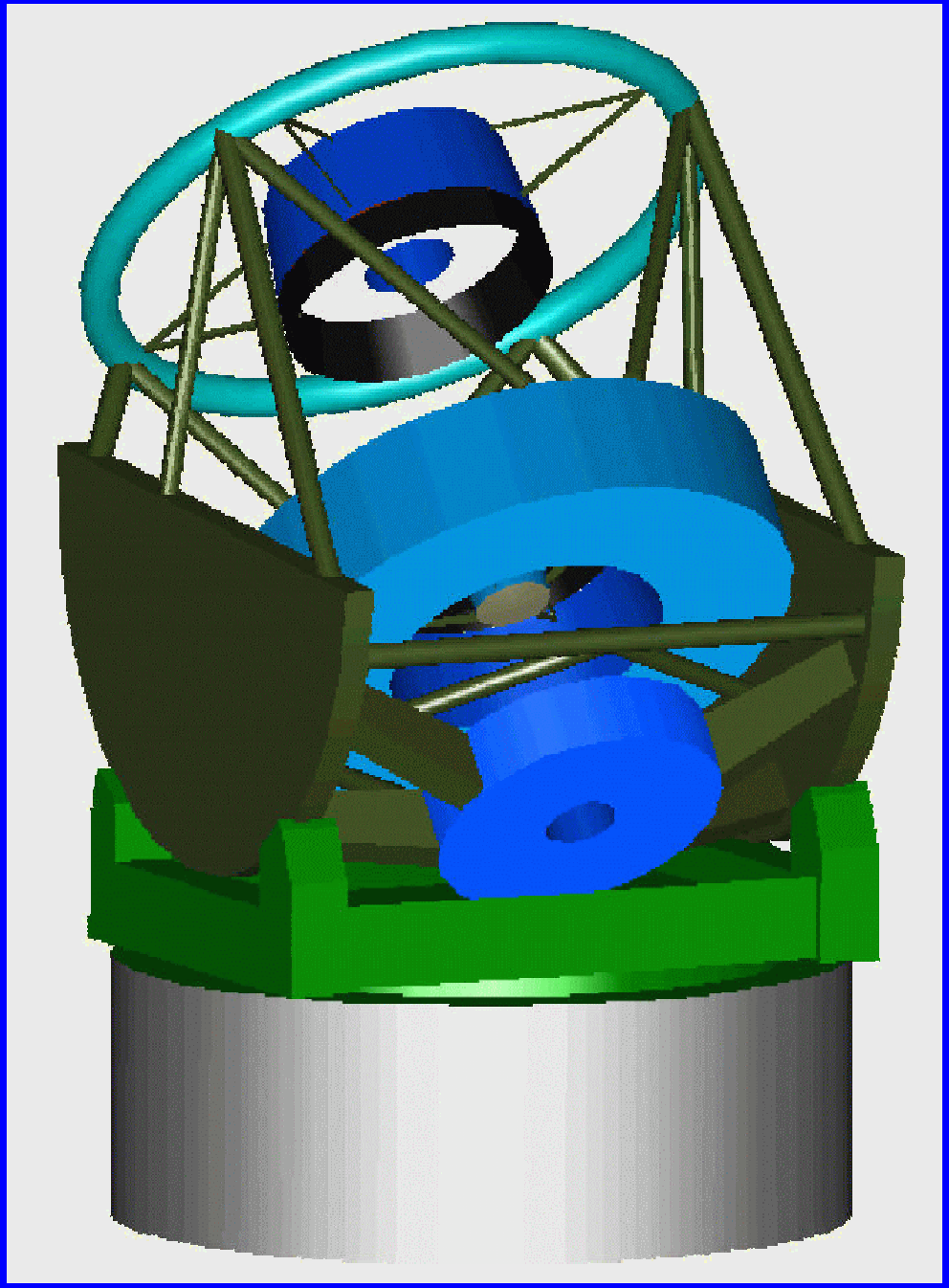
Large Synoptic Survey Telescope

Proposed 8.5m ground based telescope with 7 sq. degree field

5 Tbytes/night of data

Real-time analysis

“Celestial Cinematography”



Key Questions: Quarks to the Cosmos

2. How did the Universe begin? Did an epoch of primordial inflation give rise to the Large-scale structure of the Universe? If so, what can we learn about physics at 10^{15} GeV?

Gravity Waves from Inflation:

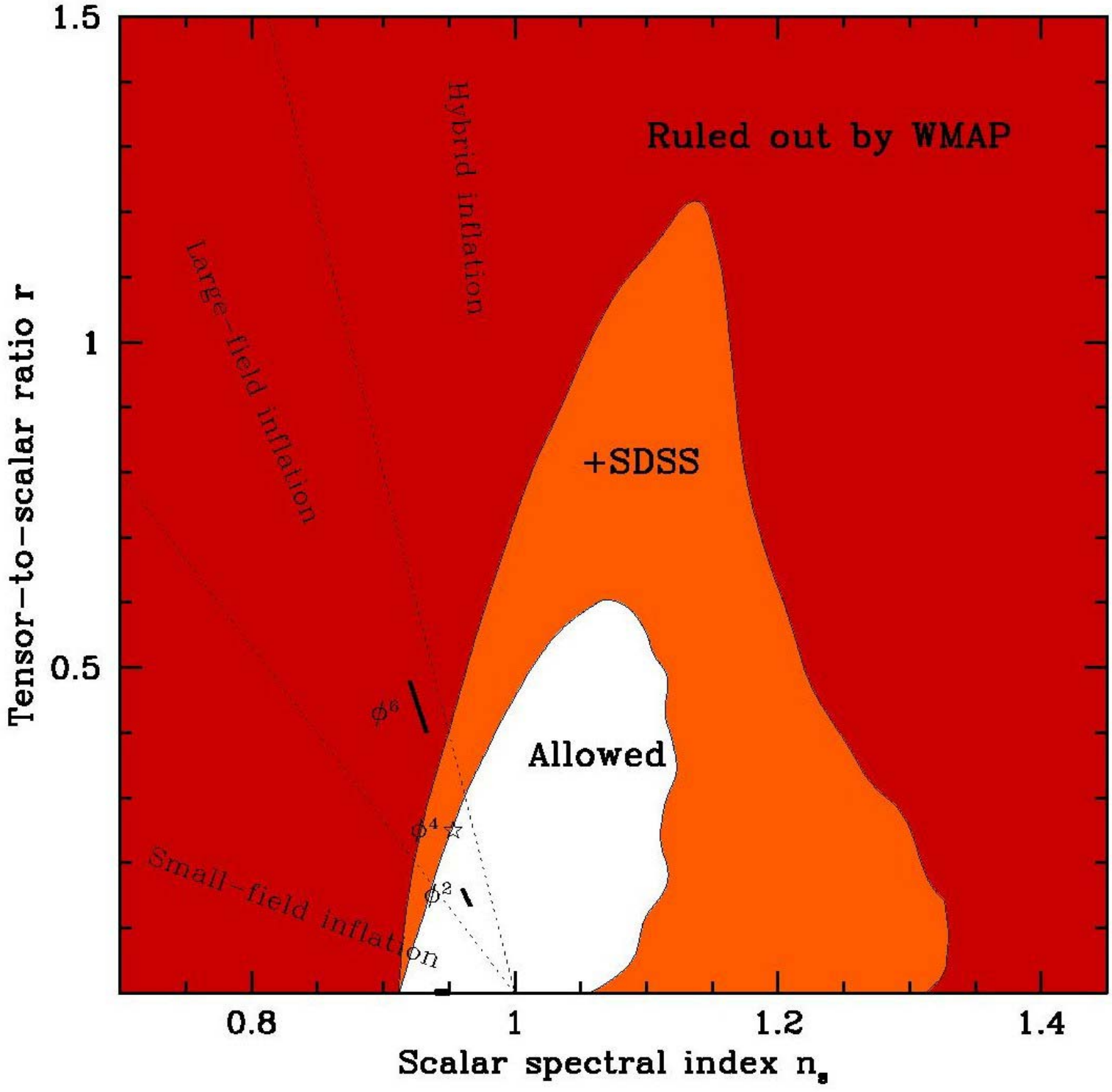
- CMB polarisation mission (B modes)
- Direct detection (LIGO→LISA→Big Bang Observer)

3. What is the Dark matter?

- Accelerator probes for SUSY, etc
- Direct detection experiments (CDMS,…)
- Indirect detection experiments (IceCube,…)
- LSS/lensing probes of DM properties (mass, interactions, decays,…)

CMB Polarization B-modes:

Probe down to $r < 10^{-3}$ - 10^{-5}



LISA

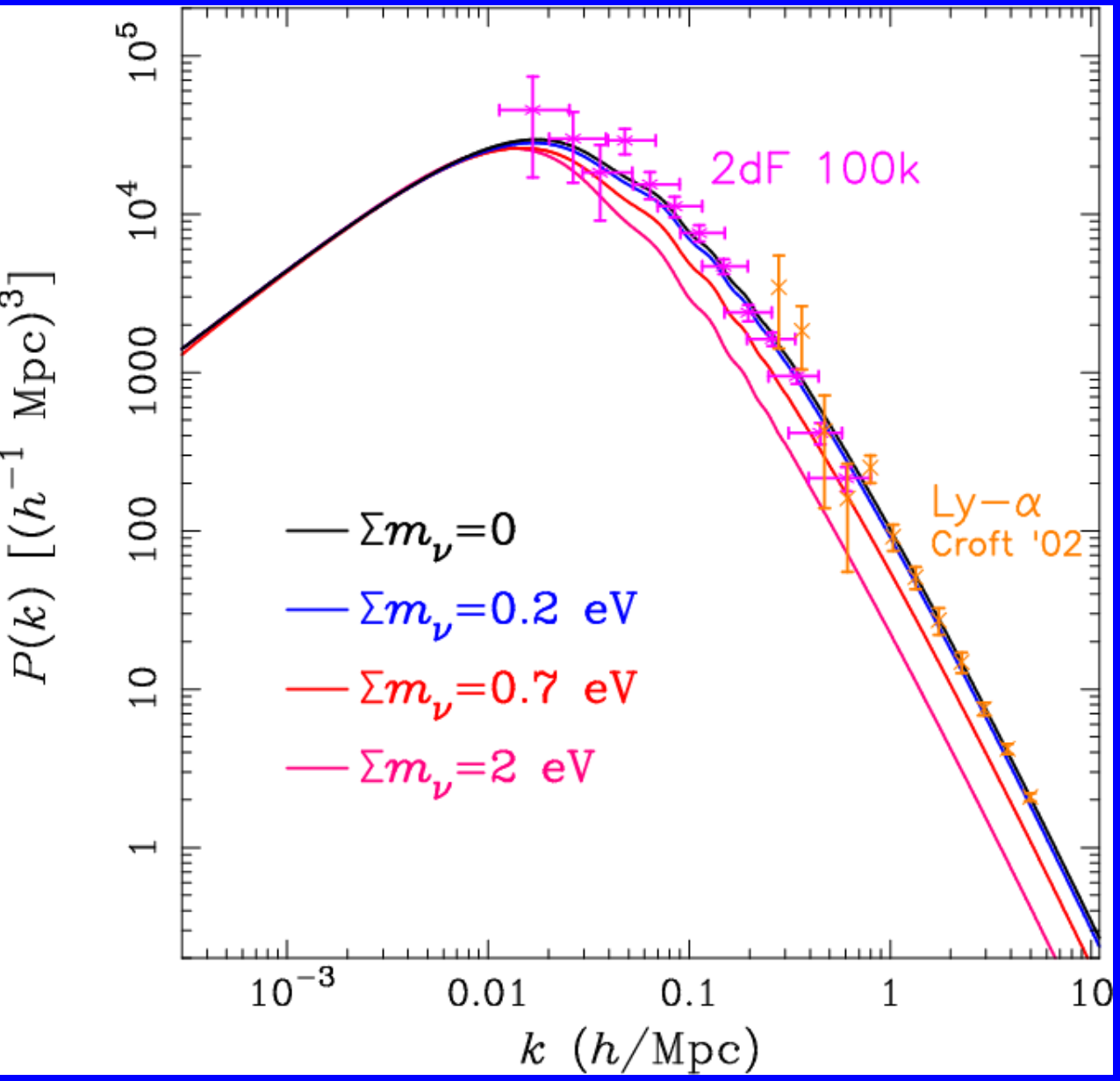
Key Questions

4. What are the masses of the light neutrinos and how have they shaped the formation of structure in the Universe?

   Large-scale matter power spectrum from galaxy surveys and weak gravitational lensing surveys

   Determining neutrino masses also important for removing degeneracies in other cosmological parameters

Neutrino Dark Matter



(graphic from Kev Abazajian)

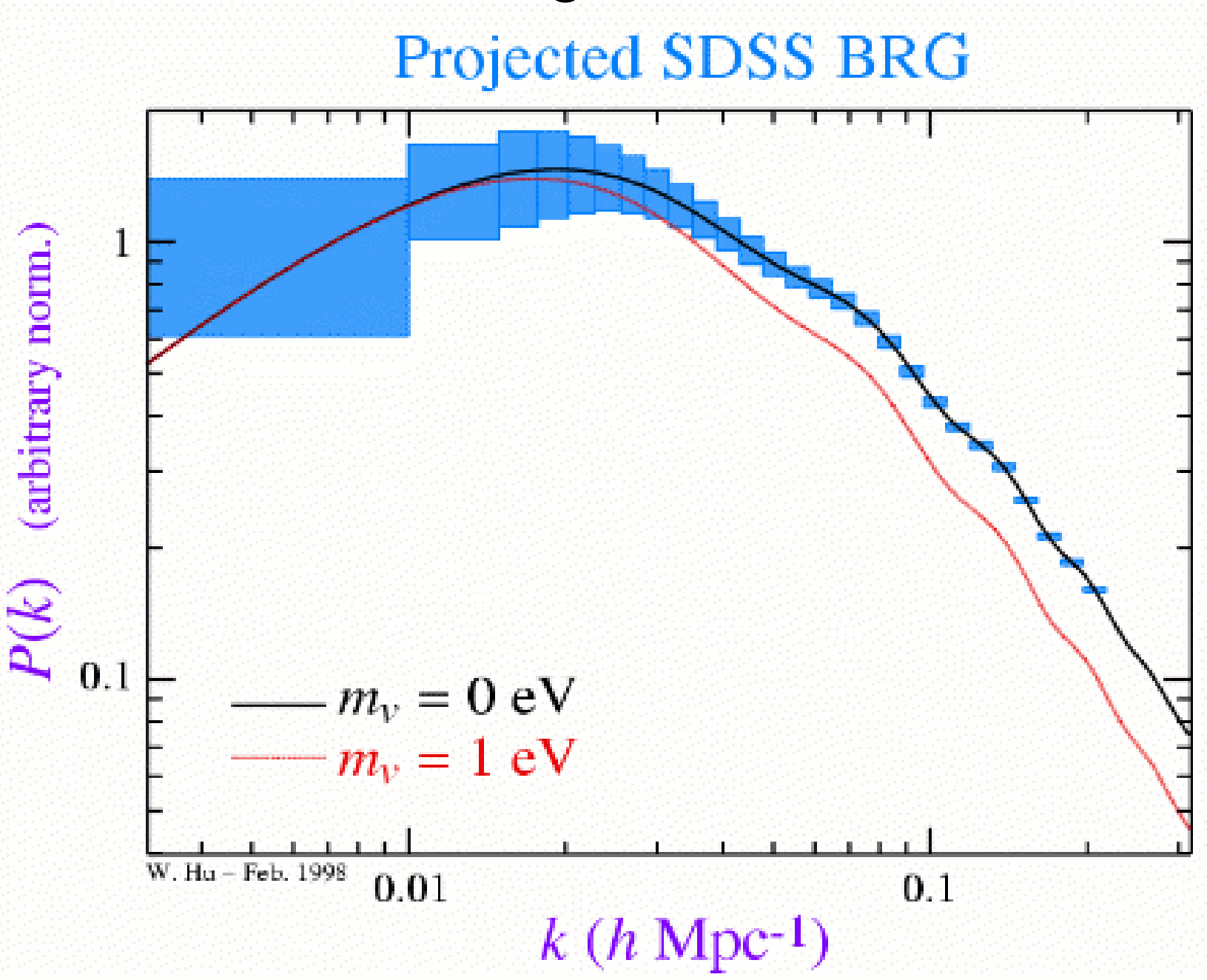
$$\rho_{matter} = \rho_{CDM} + \rho_{baryons} + \rho_{neutrinos}$$

$$\rho_\nu = m_\nu n_\nu$$

Future discovery range:
Abazajian & Dodelson,
PRL 91, 041301 (2003)

Kaplinghat, Knox & Song,
astro-ph/0303344

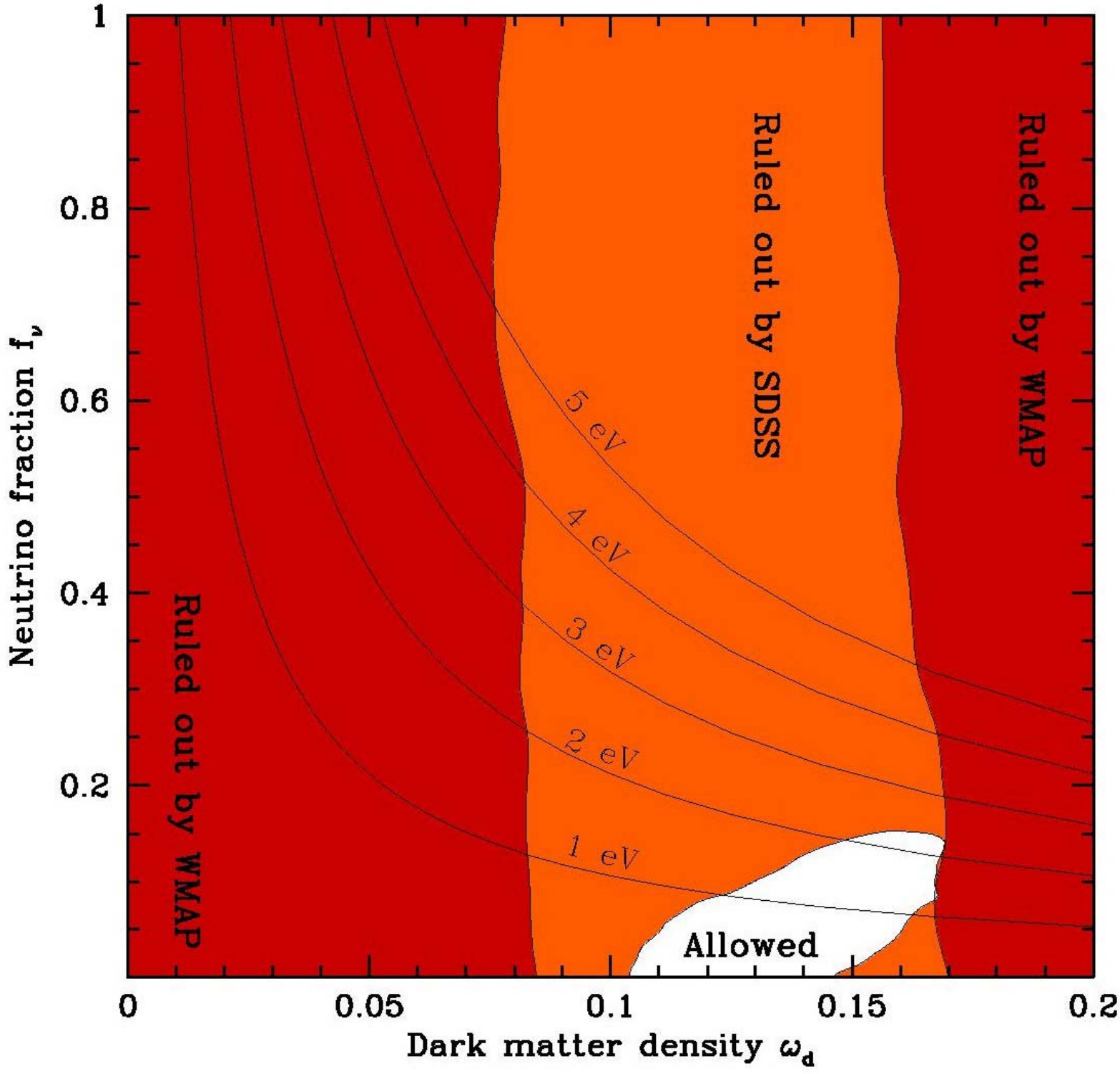
Probing Neutrino Mass



SDSS + WMAP: will constrain sum of stable neutrino masses as low as ~ 0.5 eV

$\Sigma m_\nu < 1.7$ eV

(95% CL)



Key Questions

5. What is the nature of the Ultra-high Energy Cosmic Rays?
   How do cosmic accelerators work, where are they,
   and what are they accelerating?

   Top-down scenarios: GUT-scale physics

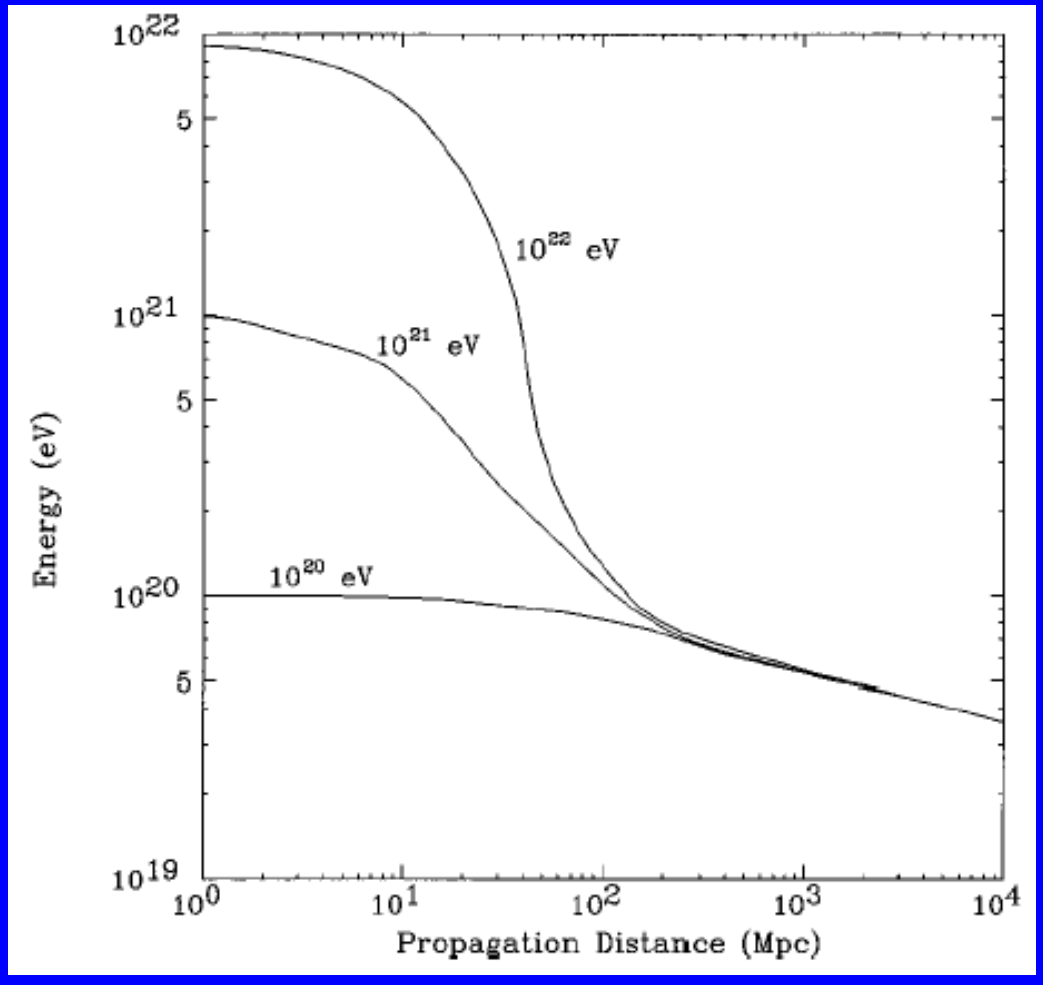
   UHE neutrinos

   Auger and beyond

GZK Neutrinos

$$p_{CR} + \gamma_{CMB} \rightarrow \Delta \rightarrow p + \pi^0 \qquad \pi^0 \rightarrow \gamma\gamma$$

$$\rightarrow n + \pi^+ \qquad \pi^+ \rightarrow \mu^+ \nu_\mu$$

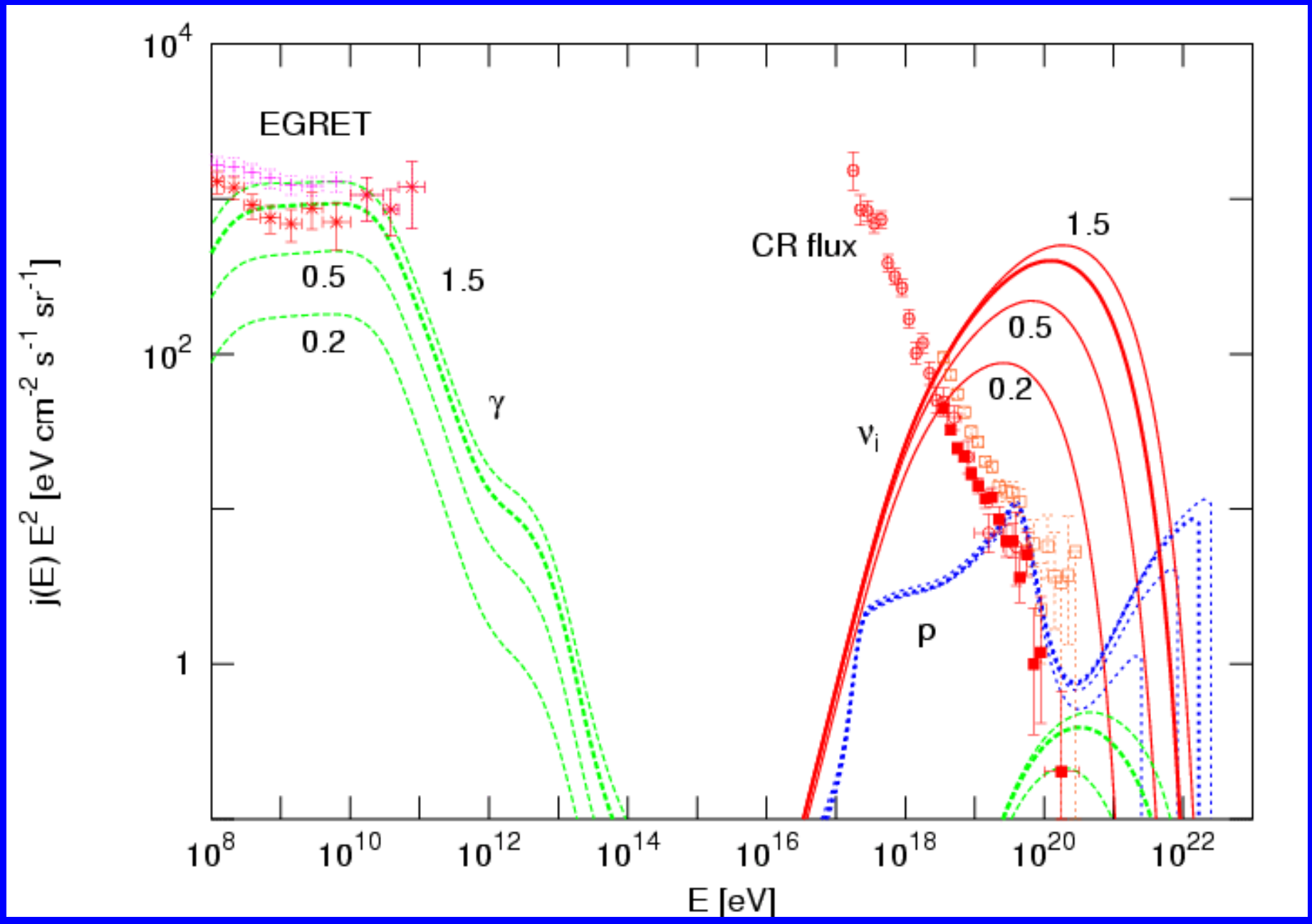


Connected observables:

- Protons
- Photons
- Neutrinos

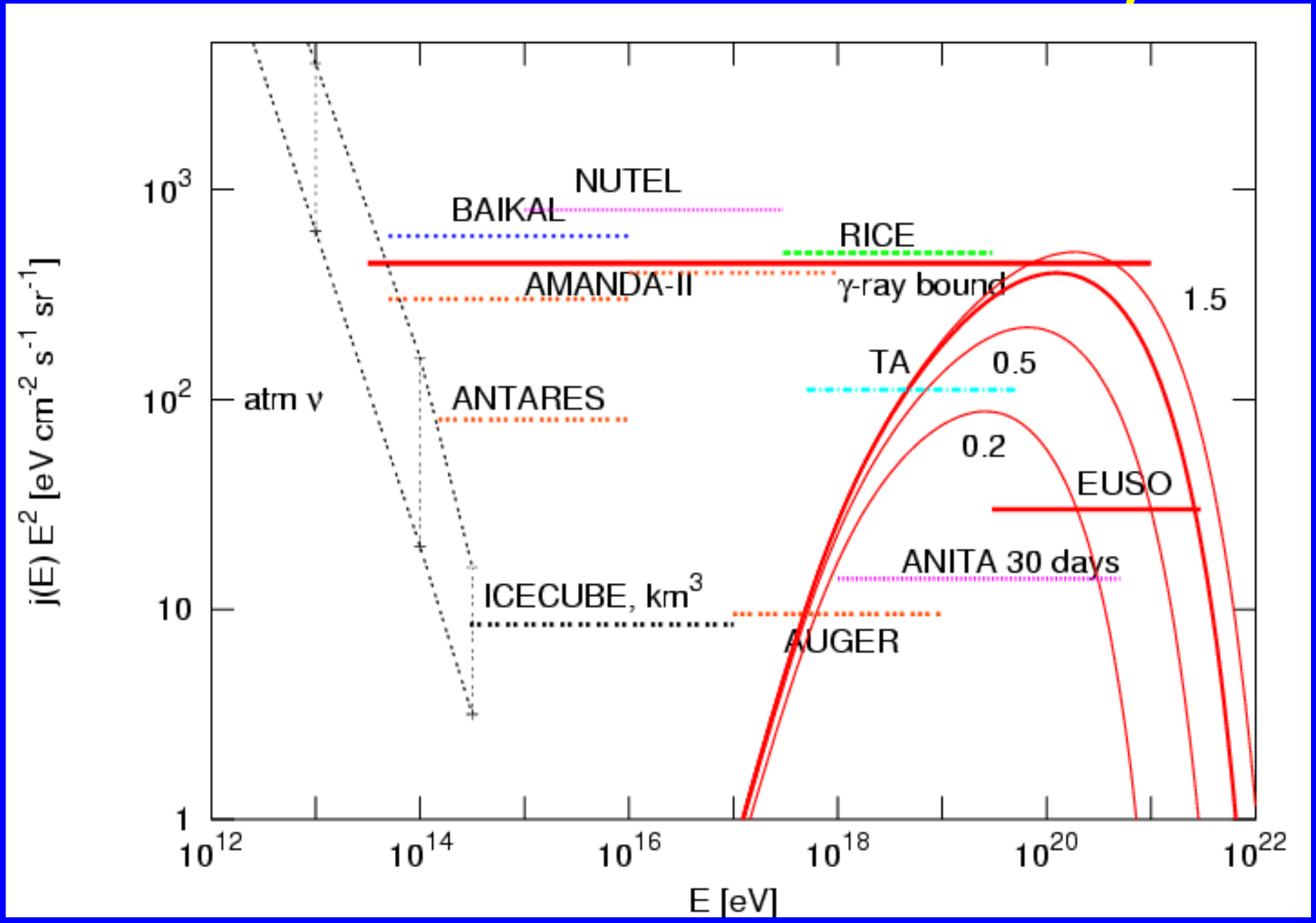
Cronin

Protons, Photons, and Neutrinos



Semikoz, Sigl, hep-ph/0309328

Future Neutrino Sensitivity



Semikoz, Sigl, hep-ph/0309328

Further Questions

6. What is the behavior of Gravity in the vicinity of Black Holes?

Constellation X, Black Hole Imager,…

7. How/when did the first stars and galaxies form?

ALMA, SKA, …. Radio telescope arrays

30-meter optical telescopes

National Initiatives/Priorities

1. Connecting Quarks to the Cosmos (NRC Report)
   NASA/DOE/NSF

2. Astronomy & Astrophysics Decadal Survey 2000

3. Beyond Einstein (NASA Roadmap)

4. HEPAP Report

5. SAGENAP Reports